AN OPERATIONAL TROPICAL ANALYSIS SYSTEM

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ABSTRACT

This paper presents the results of 5 months of an experimental operational tropical analysis scheme. The grid is a 5° of longitude square on a Mercator map. The array size is 72×23 or approximately 48°N. to 48°S. completely around the earth. The analysis has been firmly meshed into the high latitude analysis and is made at the 700-, 500-, 300-, 250-, and 200-mb. levels.

The scheme is similar to that reported by Bedient and Vederman. The current output fields are the wind and streamfunction. Pressure and temperature will be added. In conjunction with the analysis an effort has been made to increase the input of aircraft data and to improve quality control and the results will be shown. Some experiments have been made in using satellite cloud pictures to improve analysis in poor data areas. This can be of special benefit in getting a proper description of the Southern Hemisphere westerlies.

1. INTRODUCTION

The National Meteorological Center (NMC) has been running an analysis for the strip 48°N. to 48°S., which includes the entire tropical area. This strip extends completely around the earth and has cyclic continuity between the left and right edge. Since the operation is changing from time to time, this will be a discussion of the operation as of April 1, 1967. The purpose of the analysis is to extend the area of NMC operations to cover some areas not previously adequately supported and to lay the groundwork for further model development directed toward true global operation.

Currently five levels are being analyzed at 00 and 12 GMT for the u, v components of the wind, the streamfunction being obtained from these analyzed components, which in general are divergent. The levels analyzed are 700, 500, 300, 250, and 200 mb. Displays of the analysis are output in four 90° long. panels by Digifax at a 1:20 million scale. (See fig. 1.) These displays show the streamfunction and isotachs. The isotachs are derived from the analyzed u and v components of the wind and do not necessarily agree with the streamfunction gradients. The wind direction is also well described by the streamfunction.

The method of analysis, which is similar to that reported by Bedient and Vederman [1], is a version of the Cressman [3] analysis scheme that in turn is a variation of the method of Bergthórssen and Döös [2]. The continuity from one time to another is carried in the streamfunction. The first guess procedure will be described in detail later. The use of satellite data to control and modify the analyses is also described later. The grid distance is 5° of longitude on a Mercator map. This is approximately 500 km. at the Equator. This is a rather coarse grid but for the greater part of the region the quality and density of the data do not warrant finer resolution at the present time. The array of winds is 72×23 points with the 12th row on the Equator. Each column lies on an even 5° of longitude.

2. ANALYSIS PROCEDURES

In order to assure continuity at the northern boundary with the NMC high latitude analysis described in [3, 4] wind data are melded with the tropical analysis first guess for eight rows at 700, 500, and 300 mb. This is done by first obtaining the u and v wind components from the tropical streamfunction and differencing as shown in figure 2. Notice on this figure that the streamfunction is defined for points intermediate between the points where u and v are defined. The u and v components of the geostrophic wind are also obtained from the NMC octagon operational analysis for the first eight rows of the tropical grid. The u and v guess fields for the tropical grids are then formed for the eight rows by the following relations:

$$u=\alpha u_t+(1-\alpha)u_o$$

$$v=\alpha v_t+(1+\alpha)v_o,$$

where u_t and v_t are the components in the tropical grid, u_o and v_o are the components from the interpolated NMC octagonal grid, and α is a number that goes linearly from 1.0 in row 15 to 0.0 in row 23. Thus the wind guess is 100 percent tropical at approximately 15°N. and 100 percent from the NMC octagon at 48°N. Even though the geostrophic winds are not very reliable at 20°N., they get very lightweight in this region.

Above 300 mb. the guesses are extrapolated from below and then modified in the north, a procedure which improves the vertical stacking of extratropical systems and allows the continuity controls to be more effective.

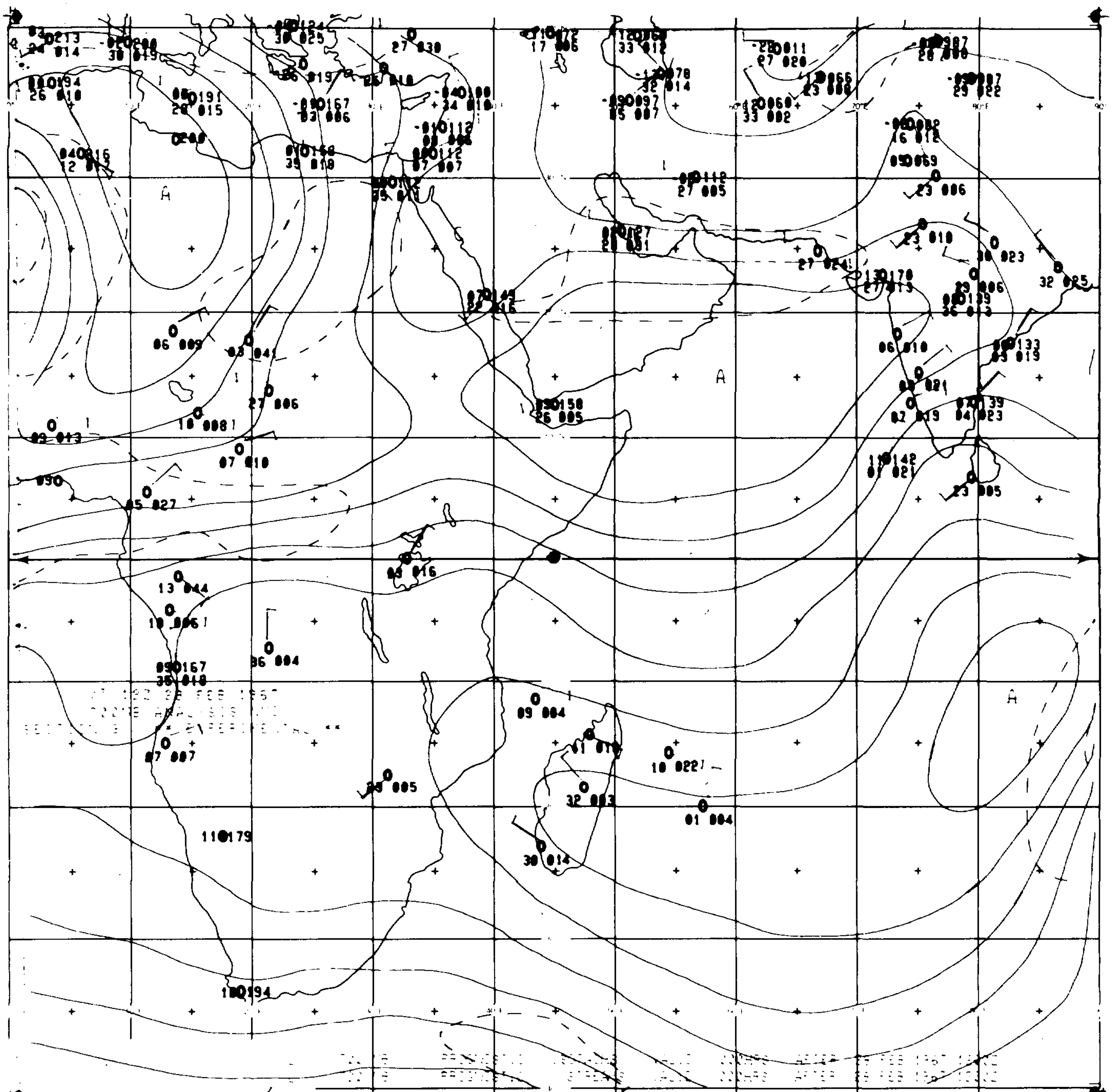

FIGURE 1.—Digifax output of analysis for 90° of longitude showing streamlines and isotachs.

Data north of 40°N. are not used in the analysis because their large volume unnecessarily loads the data bins and the data appear to disturb the adjustment the analysis already has to data that are outside the grid.

It was mentioned that the analysis is designed so as to reduce the divergent component of the analyzed wind. Since the first guess is carried in a stream field, modified in the north, even the first modification of the guess by the data is relatively nondivergent. From the u's and v's from this first pass, a streamfunction is obtained that is used for the first guess to the second pass. In this manner a relatively nondivergent u and v analysis is obtained, from which isotachs and a streamfunction are calculated. The procedure of u, v analysis followed by a calculation of a streamfunction followed by recalculation of a u, v analysis can be regarded as a form of smoothing of the data to reduce spurious divergence caused by the interaction of accidental data placement. In the end the u and v fields are not smoothed so there is divergence to the u and v fields.

The grid and difference forms used to calculate the streamfunction are shown in figure 2. The streamfunction

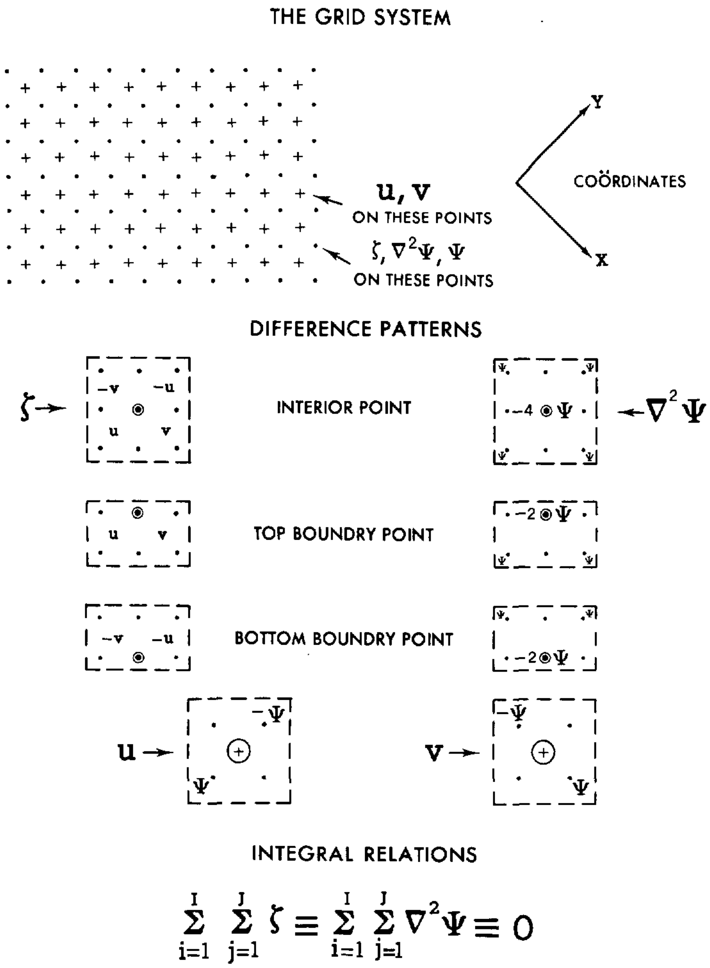

FIGURE 2.—Finite difference scheme.

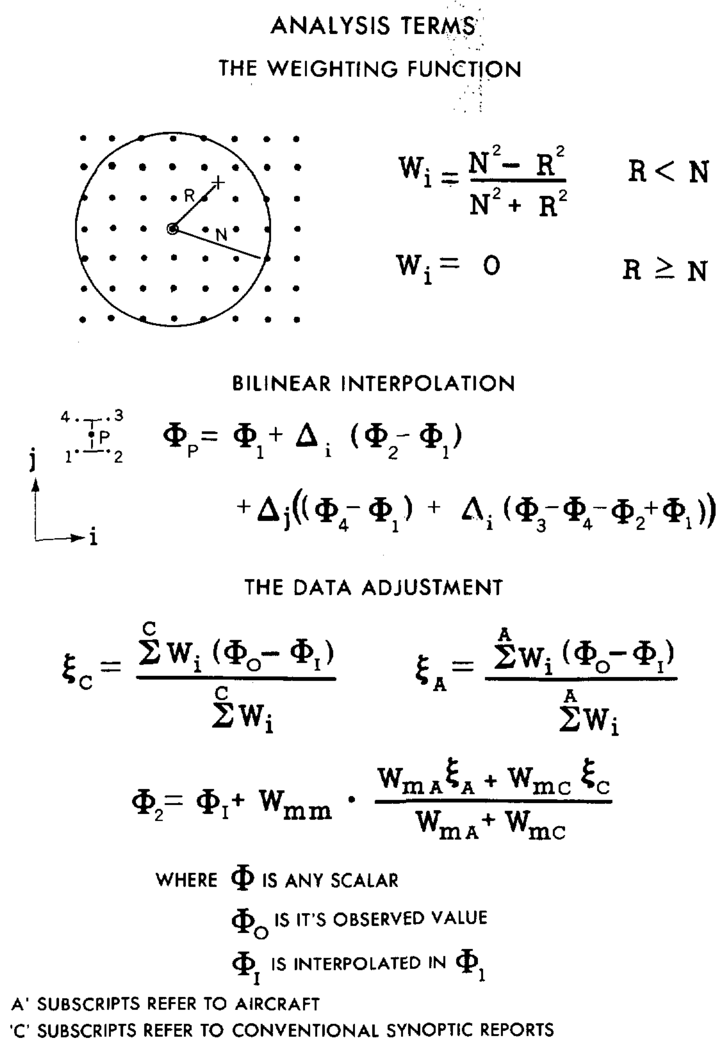

FIGURE 3.—Analysis procedure.

ψ, Laplacian $\nabla^2\psi$, and vorticity ζ are defined on the intermediate points indicated by dots. The wind components u, v are defined on the points shown with crosses. The x- and y-axes are taken at 45° to the north-south, east-west lattice so that the y-derivative of the streamfunction for instance, is the difference between two diagonal points. With the differences defined as in figure 2, the sum of the vorticity on the interior and boundary is identically zero in the finite difference equation. The sum of the Laplacian over the interior and boundary points is also zero. And if the residue during a scan is $\nabla^2\psi^1 - \zeta = \text{res}$ and the correction is $\alpha(\nabla^2\psi^1 - \zeta) = \text{cor}$ then it can be seen that Σ res$=0$ and Σ cor$=0$. This means that the mean value of the field will not change during a relaxation pass. This condition must be satisfied in the finite difference formulation so that the streamfunction may be solved from the vorticity by relaxation when the Neumann boundary condition is used.

The definition of terms in the analysis scheme is shown in figure 3. To analyze a particular grid point all the data for a distance N from that grid point are considered. R is the distance of a particular data point to the grid point. All interpolations are bilinear as shown in figure 3. The weighting function is the one introduced by Cressman [3]. The weighting function for airplanes is modified by the proportional distance from the level concerned. The airplane report is used in the two adjacent data surfaces by adjusting its winds with the 700- to 300-mb. shear. For example, an airplane at 14,000 ft. would have his wind report adjusted to 700 and 500 mb. but he would be given half the weight a report exactly on these levels would be given. No adjustment is made at present for off-time reports.

The total correction for a grid point is also shown in figure 3. It combines the aircraft into one element at a weighted distance from the grid point equal to the nearest aircraft report and combines the conventional data along with satellite bogus information to be described later into a weighted value appropriate to the nearest conventional data. The total is then summed and used at the effective distance of the nearest observation.

This scheme, which was arrived at largely by trial and error, has the following characteristics: 1) It causes an isolated piece of data to give a change which is smoothed into the surrounding area. 2) It prevents a large number of airplane reports from suppressing an isolated piece of

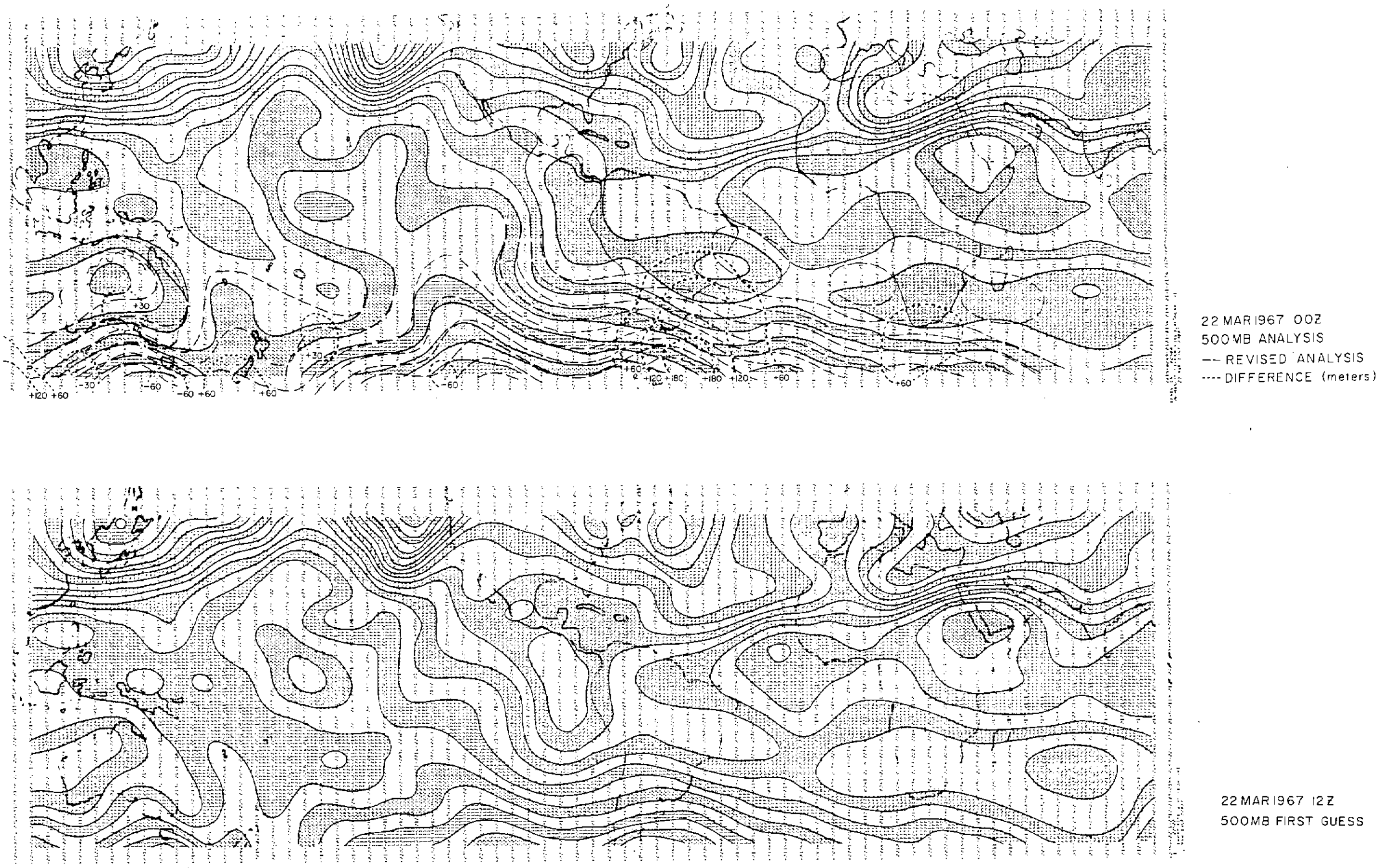

FIGURE 4.—500 mb., March 22, 1967, 00 GMT streamlines, revised streamlines, difference patterns, and first guess for March 22, 1967, 00 GMT.

conventional data. 3) It uses off-level airplanes with full weight in otherwise isolated areas, but reduces their effect in areas of heavy traffic. The influence of a piece of data is cycled in the east-west direction, thus effectively eliminating these boundaries and corrects one problem encountered at Honolulu [1] that resulted from the difficulty of treating the corners in an exact manner.

3. DATA CONTROL

The current data error control is based on tests of the data error at each analysis pass. Large errors may be tolerated in high latitude regions while very small errors may be damaging in the light wind regions. For this reason a varying criterion is used for the acceptable vector difference between the first guess and a reported wind. At present the principal data control is given by manipulation of the guess field as described later in this paper. The current tolerable vector error is given by table 1.

TABLE 1.—*Tolerable vector error (knots)*

SCAN	GUESS SPEED		
	30	60	90
1	60	75	90
2	50	62	75
3	40	50	60
4	30	37	45

4. SATELLITE UTILIZATION

Satellite-derived information is being used in two ways to augment the meteorological data used by the analyses. In the equatorial and tropical regions, winds are being estimated from cirrus blowoff. The direction of the cloud plume strictly represents a combination of movements of various portions of the cloud, but with a small error, the plume may be assumed to line up with the upper winds, say 200 mb. While directions obtained in this manner are generally reliable, the speeds are more difficult to estimate, and several factors are taken into account, including the length of the plume, the latitude, nearby observations, persistence, and climatology. As mentioned before, these winds are entered directly as bogus information and are used by the analysis just as any other piece of information. These winds are entered at 300, 250, and 200 mb. Each 12 hr. the winds are updated for half the tropical strip using the latest satellite pictures, while the older winds are used for the second half except near the westerlies where systems move too rapidly for old satellite winds to be useful.

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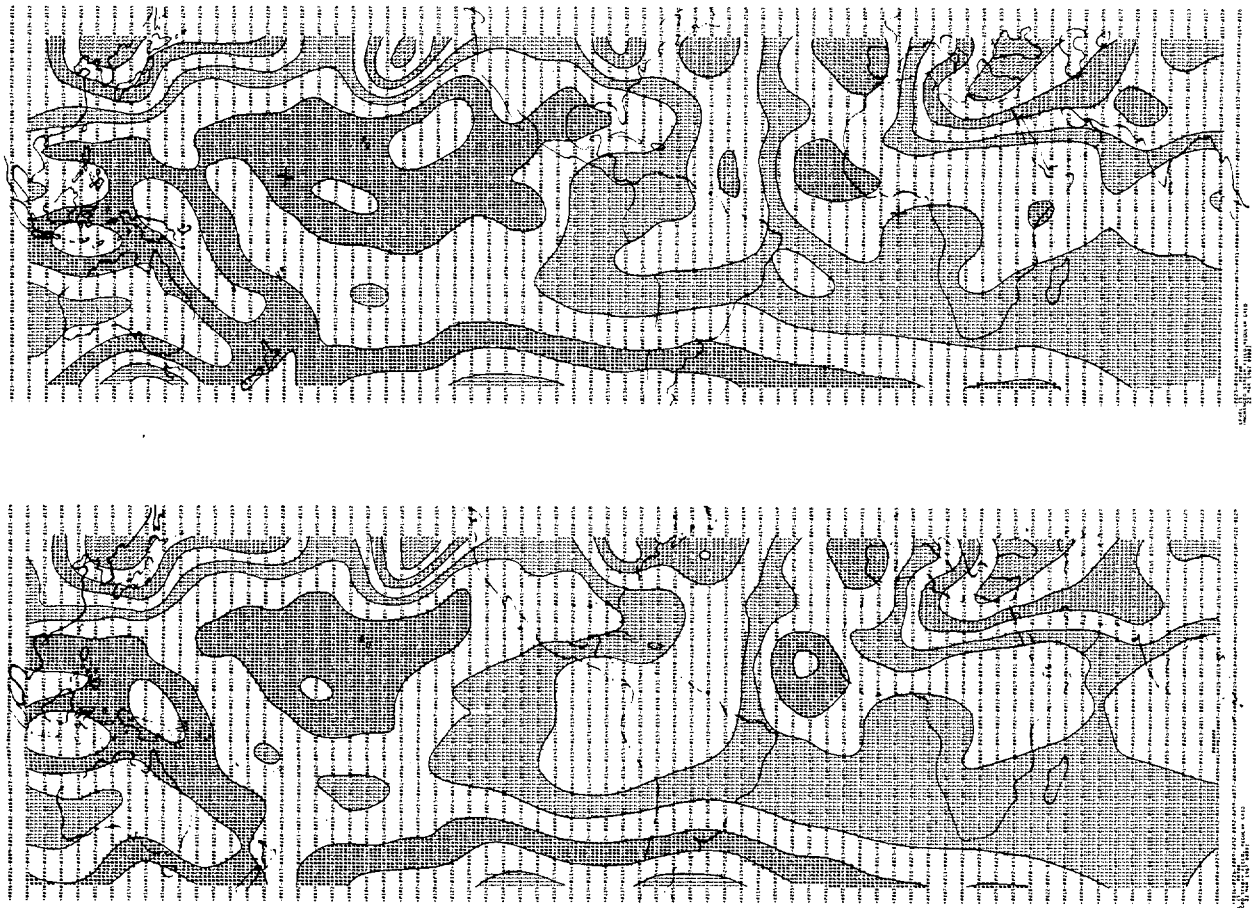


FIGURE 5.—700 mb., March 22, 1967, 00 GMT streamlines and 12 GMT first guess.

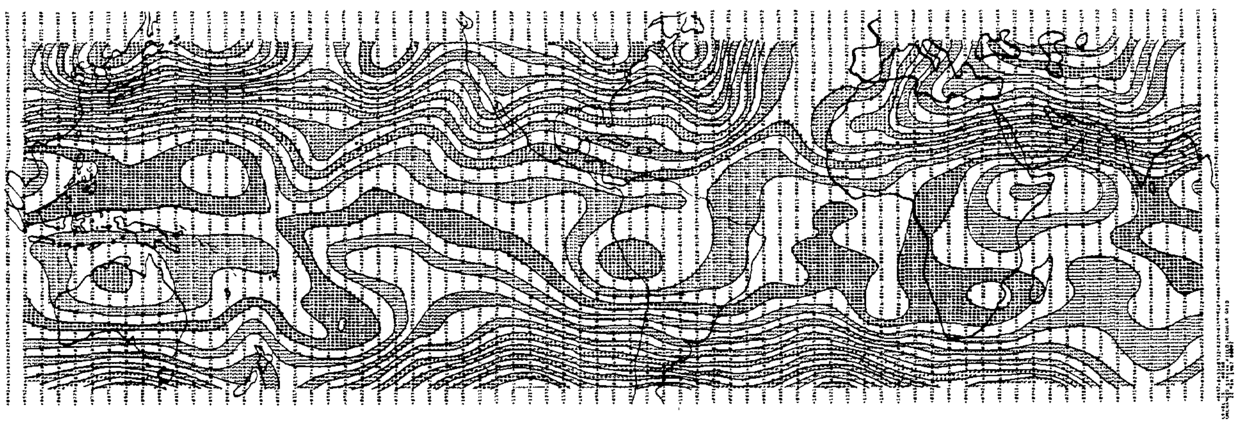
Satellite-derived information is also used during the first-guess procedure. For several years the National Environmental Satellite Center has been estimating the positions of troughs and ridges, jet positions, centers of systems, and relative strengths of systems in the Northern Hemisphere westerlies. It is assumed that these same relationships hold true in the Southern Hemisphere.

Since the cloud photos are not received for the whole globe at data time, the positions of systems, etc. from photos must be used to correct the last analysis rather than as input for an up-coming analysis. In this sense, this information is used in preparing the first guess.

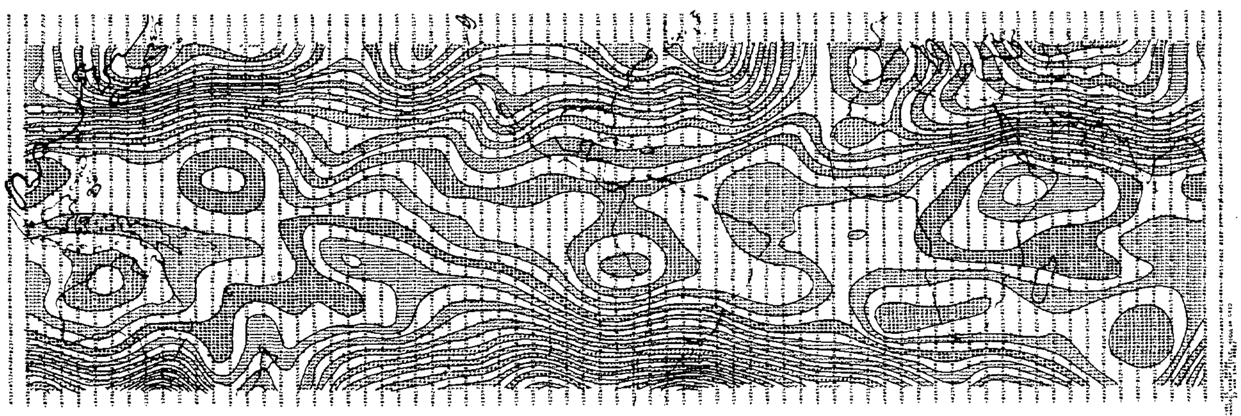
Using the satellite position of systems in the Southern Hemisphere westerlies and any other available information, an analyst subjectively makes a revised 500-mb. streamfunction analysis. In figure 4, which shows streamfields for March 22, 1967, the subjectively revised streamfield for 00 GMT is indicated by the dashed lines on the top map. The difference patterns between the original and this revised analysis are shown by a dotted line. The values of the streamfunction are scaled in the practice at NMC by the relation $\hat{\psi}=(\bar{f}/g)\psi$ where $\bar{f}$ is the value of the Coriolis parameter at 45°N. This has the units then of height and is analogous to the practice of defining a geopotential meter as 0.98×10^7 ergs. The largest change made by the analysts in figure 4 is +180. The average change is usually much less.

It may be seen that these change patterns are approximately circular or elliptical in shape. Because this is so, the changes may be parameterized as elliptical patterns and added to the original analysis by computer. A bell-shaped curve has been chosen as the cross-section profile. The technique of choosing the parameters for each change does take some experience but is not difficult.

After applying these changes the revised 500-mb. stream analysis is used as basis for changing the 700- and 300-mb. analyses in such a way as to assure vertical consistency. This is done by increasing or decreasing the gradients in the revised 500-mb. analysis so that it has the same gradient in the southern portion as the 300- or 700-mb. analysis. Then these fields are melded with the original analyses at 300 and 700 mb. with a weighting function which goes from 0.7 at the southern boundary to 0.0 at 12.4°S. This assures rather strict vertical consistency



22 MAR 1967 00Z
300 MB ANALYSIS



22 MAR 1967 12Z
300 MB FIRST GUESS

FIGURE 6.—300 mb., March 22, 1967, 00 GMT streamlines and 12 GMT first guess.

at the southern boundary, and to a lesser degree throughout the southern westerlies. Since the conventional observations are so scarce in this region, there is also applied a 10 percent return to the climatological shear each 12 hr. The winds themselves are also given a 10 percent return to climatological vector winds to prevent cumulative increase of the winds.

From these revised 700-, 500-, and 300-mb. analyses a 12-hr. forecast is made using a barotropic filtered equation model in order to obtain a first guess for the next analysis. The 500-mb. first guess for 12 GMT March 22, 1967, is shown in the lower portion of figure 4. Figure 5 shows the 700-mb. 00 GMT analysis and 12 GMT first guess for March 22, 1967. Figure 6 is for 300 mb. In all these figures it may be noticed that the changes between the 00 GMT analysis and the 12 GMT first guess are: 1) amplification and movement of the Southern Hemisphere trough to the east of South America, 2) modification to the trough southeast of Africa, and 3) more amplitude in the systems southeast of Australia. From these three first guesses and, of course, data, the 12 GMT analyses are obtained as shown in figure 7. The vertical stacking of the systems in the Southern Hemisphere westerlies is quite good.

Figure 8 shows the 500-mb. analysis for 12 GMT March 22, 1967, superimposed upon the cloud photo mosaic that is true in time at about 30° W. The systems in both hemispheres show reasonably good to excellent correspondence with the analyzed flow pattern. The fronts are all in agreement with the troughs. The jet across Africa is in excellent position. The tropical storm and the closed Low in the Pacific Ocean are also shown very well.

5. EVALUATION

Some problems have been experienced with the analysis. Early in the operational period, little control was being exerted on the analysis, thus allowing unreasonable flows. Integral contraints do specify no net cross-equatorial flow, for instance, but large compensating flows are possible. The inclusion of satellite information attempts to specify where these flows are, if they are present. This information also helps to confine the jet streams into each hemisphere by more correctly specifying

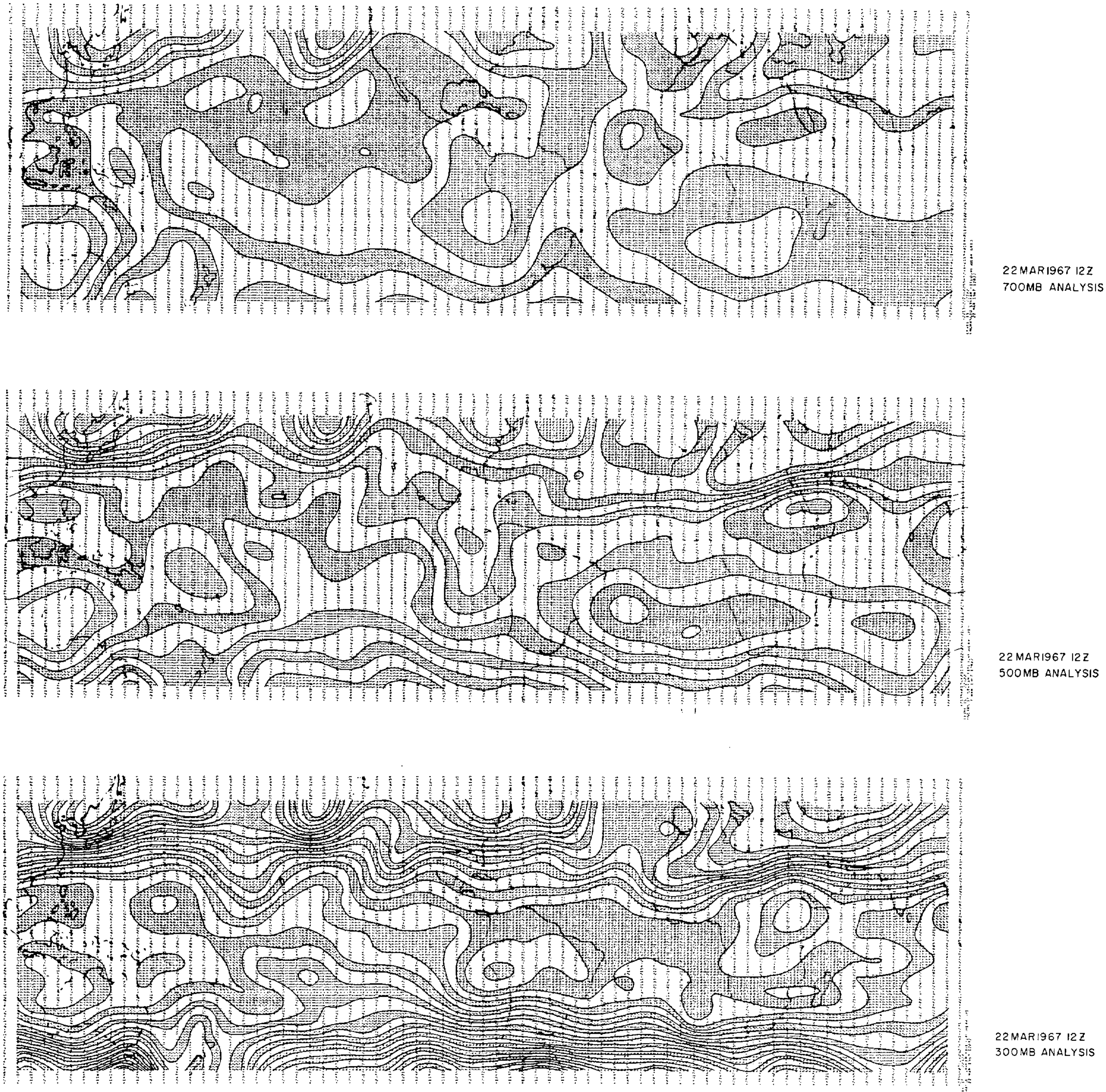


FIGURE 7.—12 GMT, March 22, 1967, streamline analyses for 700 mb., 500 mb., and 300 mb.

the weak medium-scale features in the inter-tropical zone. Placement of the southern westerly troughs and ridges makes such better use of the limited data received from the Southern Hemisphere.

A deficiency of the present analysis technique concerns small-scale features such as typhoons and hurricanes. Isolated data near such small-scale phenomena tend to cause perturbations of too broad a scale in the analyses or these data may exceed the critical vector error limits and not be used at all. In the future, typhoons and hurricanes may be included as special features.

A more recent advance consists of running a "final" analysis 8 hr. after data time. Experience shows that it is very difficult to collect South American, South African,

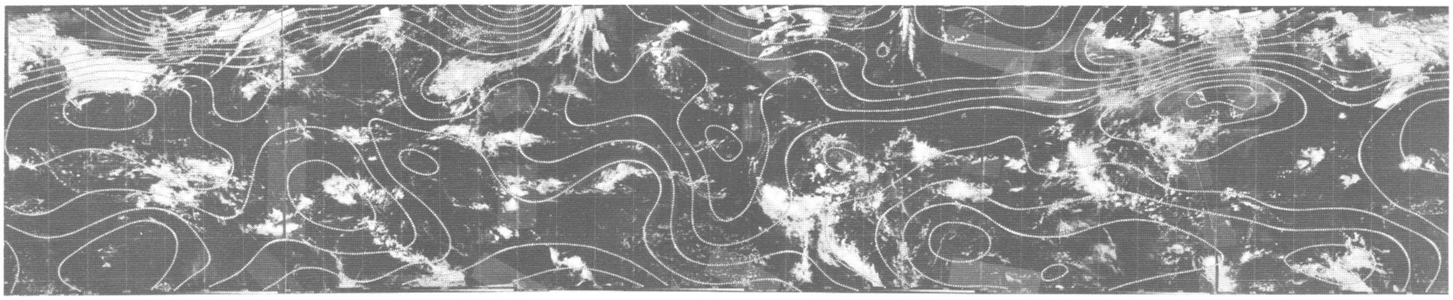


FIGURE 8.—Composite satellite cloud photos with imposed analysis streamlines for 500 mb., March 22, 1967, 12 GMT.

and South Atlantic data by 4 hr. after data time due to the long radio links involved. Since June 15, 1967, a reanalysis with later data is done before the correction procedures are applied. This gives a much more reliable base for starting the next cycle.

6. SUMMARY

In general, the NMC tropical analysis has shown con-considerable success. The Digifax displays have been distributed by facsimile as experimental products for comparison in Miami and Honolulu. A number of cogent suggestions have been made that have been, or are being, incorporated. The wind fields have been used as input to the Vanderman and Collins [5] operational experiments in tropical forecasting described in the accompanying paper.

Since March 1967 a reverse melding process from that described in preparation of the initial guess has been used to get a composite wind field valid from Pole to Equator. Winds, temperatures, and tropopause heights from the 6-level PE model are interpolated into a 10-level latitude-longitude grid at 6-hr. time intervals. The tropical wind data are then melded as 100 percent tropical to 20°N., the average of the two at 25°N., and 100 percent 6-level from 30°N. Currently, persistence is used as a forecast. This is being used operationally by the U.S. Air Force and a number of airlines as input to their flight planning schemes. Improvements are required in data coverage (that is being carried out) in better treatment of detail in dense data regions (work is in progress), and in better treatment of the level of maximum wind.

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